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FORM PTO-1390 (Modified) (REV 11-2000) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE		ATTORNEY'S DOCKET NUMBER 7616/42/5
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 10/089830
INTERNATIONAL APPLICATION NO. **PCT/US00/29822**	INTERNATIONAL FILING DATE **30 October 2000**	PRIORITY DATE CLAIMED **29 October 1999**

TITLE OF INVENTION
Increased Emission Efficiency for Organic Light Emitting Diodes

APPLICANT(S) FOR DO/EO/US
James C. Sturm, Conor F. Madigan, Min-Hao M. Lu

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☐ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include itens (5), (6), (9) and (24) indicated below.
4. ☐ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   - a. ☐ is attached hereto (required only if not communicated by the International Bureau).
   - b. ☐ has been communicated by the International Bureau.
   - c. ☒ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ An English language translation of the International Application as filed (35 U.S C. 371(c)(2)).
   - a. ☐ is attached hereto.
   - b. ☐ has been previously submitted under 35 U.S.C 154(d)(4).
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   - a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   - b. ☐ have been communicated by the International Bureau.
   - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   - d. ☐ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☐ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A copy of the International Search Report (PCT/ISA/210).

Items 13 to 20 below concern document(s) or information included:

13. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☐ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
21. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22. ☒ Certificate of Mailing by Express Mail
23. ☐ Other items or information:

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U.S. APPLICATION NO (IF KNOWN, SEE 37 CFR	INTERNATIONAL APPLICATION NO.	ATTORNEY'S DOCKET NUMBER
10/089830	PCT/US00/29822	7616/42/5

24. The following fees are submitted:.

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

- ☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO **$1040.00**
- ☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO **$890.00**
- ☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO **$740.00**
- ☒ International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) **$710.00**
- ☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**

				CALCULATIONS	PTO USE ONLY
ENTER APPROPRIATE BASIC FEE AMOUNT =				**$710.00**	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).				**$130.00**	
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	20 - 20 =	0	x $18.00	**$0.00**	
Independent claims	6 - 3 =	3	x $84.00	**$252.00**	
Multiple Dependent Claims **(check if applicable).**			☐	**$0.00**	
TOTAL OF ABOVE CALCULATIONS =				**$1,092.00**	
☒ Applicant claims small entity status. See 37 CFR 1.27). The fees indicated above are reduced by 1/2.				**$546.00**	
SUBTOTAL =				**$546.00**	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). +				**$0.00**	
TOTAL NATIONAL FEE =				**$546.00**	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).** ☐				**$0.00**	
TOTAL FEES ENCLOSED =				**$546.00**	
				Amount to be: refunded	$
				charged	$

a. ☐ A check in the amount of ________ to cover the above fees is enclosed.

b. ☒ Please charge my Deposit Account No. **06-2143** in the amount of **$546.00** to cover the above fees. A duplicate copy of this sheet is enclosed.

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NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

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REGISTRATION NUMBER

4 April 2002
DATE

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Box PCT
Assistant Commissioner for Patents
Washington, D.C. 20231

Re:	Our file:	7616/42/5	Examiner:
	Applicant:	Sturm, et al.	Office:
	Serial No.:	PCT/US00/29822	
	Filing Date:	30 October 2000	
	Title:	Increased Emission Efficiency for Organic Light Emitting Diodes	

Sir:

Enclosed for filing in the United States Patent and Trademark Office is the following:

1. Transmittal Letter to the United States Designated/Elected Office (DO/EO/US) Concerning a Filing Under 35 U.S.C. 371
2. Transmittal Sheet
3. Postcard Receipt

CONDITIONAL PETITION

If any extension of time is required for the submission of the above-identified items, Applicant requests that this be considered a petition therefor. Please charge any additional charges or any other charges relating to this matter to the deposit account of the writer, **Account No. 06-2143**. A duplicate copy of this letter is enclosed.

Respectfully submitted,

4 April 2002
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I hereby certify that this correspondence is being deposited with the United States Postal Service, postage prepaid, as "Express Mail Post Office to Addressee," Mailing Label No. EL548969248US to Box PCT, Assistant Commissioner for Patents, Washington, D.C. 20231 on 4 April 2002

By: ______________
Michael R. Friscia

ORGANIC LIGHT EMITTING DIODE HAVING SPHERICAL SHAPED PATTERNS

SPECIFICATION

BACKGROUND OF THE INVENTION

RELATED APPLICATIONS

The present invention is related to and claims the benefit of U.S. Provisional Patent Application Serial No. 60/162,552, filed October 29, 1999 and entitled "Improvement of Output Coupling Efficiency of Organic Light Emitting Diodes by Backside Substrate Patterning", which provisional application is assigned to the same assignee and is incorporated by reference herein.

FIELD OF THE INVENTION

This invention relates to the field of light emitting devices, and more particularly to organic light emitting devices (OLEDs) and the emission efficiency thereof.

PRIOR ART

Access to the Internet and the need to download and view vast quantities of data at greater and greater speeds, along with a frequent requirement for portability and a small footprint are placing greater demands on the capabilities of display devices. The display device of choice for such applications is a flat-panel display, but the current liquid crystal display (LCD) technology in use by most flat-panel displays is limited in its ability to meet these increasing demands. A new display technology, however, offers considerable promise for overcoming the limitations of the LCD technology. That new technology is based on the application of organic light-emitting diodes (OLEDs), which make use of thin film materials that emit light when excited by an electric current.

The typical OLED consists of a multi-layer sandwich of a planar glass substrate (t_{sub} ~ 1mm, n_{sub} = 1.51), a layer of Indium Tin Oxide (ITO) (t_{ITO} ~ 100 nm, n_{ITO} ~ 1.8), one or more organic layers (t_{org} ~ 0.1 nm, n_{org} = 1.6 - 1.8), and a reflecting cathode (e.g. Mg:Ag or Li:Al), where t refers to the layer thickness and

n refers to the layer index of refraction. For simplicity, the discussion herein will be based on a single organic layer, where the light emission occurs. However, those skilled in the art will readily understand that the discussion and analysis that follows can readily be extended to more complicated device structures.

An important figure of merit for a display system is the efficiency of conversion of input power to emitted light. In OLED displays, a critical factor in determining this system efficiency is the coupling efficiency (η_{ext}) with which internally generated light is coupled out of the device. In order to meet expected demands of future display systems. there is a need to improve the coupling efficiency of OLEDs.

OBJECTS AND SUMMARY OF THE INVENTION

It is accordingly an object of the invention to provide an increase in coupling efficiency for OLEDs. To that end, an approach is provided for increasing the emission intensity of an organic light emitting diode (OLED) and the total external emission efficiency for an OLED at a normal viewing angle. With the approach of the invention, they have been increased by factors of 9.6 and 3.0 respectively by applying spherically shaped patterns to the back of the device substrate. The inventive approach captures light previously lost to wave-guiding in the substrate and, with proper choice of substrate, light previously lost to wave-guiding in the organic/anode layers. According to the method of the invention, a surface texturing approach is provided which, when compared with devices fabricated on typical planar glass substrates, can at least double the emission efficiency for an OLED when glass substrates are used, and at least triple the OLED emission efficiency when high index plastic substrates are used.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows ray diagrams for various light paths in a planar OLED.

Figures 2(a) and 2(b) provide a schematic depiction of the use of spherical surface features to improve light emission efficiency for an OLED according to the invention.

Figure 3(a) shows measured far field intensity distribution pattern for planar glass substrate and expected profiles of a Lambertian emitter.

Figure 3(b) shows experimental results for glass substrate devices with and without spherical surface features applied according to the invention.

Figure 3(c) shows experimental results for PC substrate devices with and without spherical surface features applied according to the invention. along with the planar glass substrate results.

DETAILED DESCRIPTION OF THE INVENTION

A novel approach is described herein for significantly improving the emission efficiency of an OLED. In the description of that approach, an analytical construct is first developed to provide an evaluation tool useful for describing the emission efficiency improvement of the invention and comparing that result with prior-art techniques. With that analytical construct in place, the approach of the invention for achieving the improved OLED emission efficiency is then described. Finally, a number of embodiments for the improved emission-efficiency approach of the invention have been implemented by the inventors. and those embodiments are described.

As described in the background section, the coupling efficiency (η_{ext}) of an OLED is a critical factor in the determination of emission efficiency for an OLED display. It is straightforward to analyze η_{ext} for the type of layered structure used in an OLED by considering the indices of refraction associated with each layer. As a predicate to that analysis, consider the ray diagram for planar OLEDs shown in Figure 1, demonstrating loss by light trapping in the substrate layer (ray II) and in the organic/anode layers (ray III). As shown by ray I of the figure, only light emitted at sufficiently small angles will escape.

Because the refraction index for the substrate is less than the organic layer refraction index (*i.e.*, $n_{subs} < n_{org}$), a critical angle, $\theta_{org,\ c2}$, can be obtained. defined by $\sin^{-1}(n_{subs}/n_{org})$. for which light emitted in the organic layer at an angle greater than $\theta_{org,\ c2}$ is wave-guided within the ITO and organic layers. This light emission path is illustrated as ray III in Figure 1. Similarly, because $n_{glass} < n_{subs}$, one can also obtain a critical angle, $\theta_{org,\ c1}$, defined by $\sin^{-1}(n_{air}/n_{org})$, for which light emitted in the organic layer at an angle greater than $\theta_{org,\ c1}$ is wave-guided in the substrate -- illustrated as ray II in Figure 1. Since only the light emitting at angles less $\theta_{org,\ c2}$ is emitted from the device -- illustrated as ray I in Figure 1, all of the remaining wave-guided light is effectively lost, representing a reduction in η_{ext}. Applying ray optics and assuming isotropic emission from a point source in the organic layer and a transmission coefficient. T, of 1 for $\theta < \theta_{org.c1}$ and 0 otherwise. one can compute η_{ext} and η_{subs}, the latter representing the fraction of emitted light which is waveguided in the substrate

$$\eta_{ext} = \int_0^{\theta_{org,c1}} \sin\theta \, d\theta = 1 - \cos\theta_{org,c1} \approx \frac{1}{2n_{org}^2} \; \textit{(planar substrate)}. \quad (1)$$

$$\eta_{subs} = \cos\theta_{org,c1} - \cos\theta_{org,c2} . \quad (2)$$

[*See*. N. C. Greenham, R. H. Friend, and D. D. C. Bradley, "Angular dependence of the emission from a conjugated polymer light-emitting diode: implications for efficiency calculations", Adv. Mat. **6**, 491 (1994)]

Furthermore, the external luminous intensity distribution, under the same assumptions, is given by

$$I_{ext}(\theta_{ff}) = \frac{F}{2\pi} \frac{n_{air}^2 \cos\theta_{ff}}{n_{org}^2 \sqrt{1 - \left(\frac{n_{air}}{n_{org}} \sin\theta_{ff}\right)^2}} \; \textit{(planar substrate)}. \quad (3)$$

[*See*, G. Gu, D. Z. Garbuzov, P. E. Burrows, S. Venkatesh, and S. R. Forrest, "High-external-quantum-efficiency organic light-emitting devices", Opt. Lett. **22**, 396 (1997)]

which resembles the cosine intensity profile of a Lambertian emitter. (Note that the above equations and modeling all ignore well-known microcavity effects that complicate the model but do not change the qualitative efficacy of the methodology and results described herein.)

It should be noted that the assumption that T=1 for $\theta < \theta_{org.c1}$ represents a simplification. In particular, it represents the upper bound on the expected emitted intensity. The lower bound (neglecting microcavity effects) can be obtained if one uses the expressions for T(θ) determined by applying the Fresnel Equations at each interface. However, the simplification can be seen to provide a close approximation. In the determination of the factors represented by equations (1), (2), and (3) for the case of T=1 for $\theta < \theta_{org.c1}$, it is implicitly assumed that all of the light internally reflected at these angles is eventually emitted, while in the second approach (lower bound) it is assumed that *none* of the internally reflected light is readmitted. The results obtained for $I_{ext}(\theta_{ff})$ in both cases, along with the cosine result obtained for a Lambertian emitter, are plotted in Figure 3a, along side the experimental results obtained for an OLED fabricated on a planar, glass

substrate. The difference between the two refraction models (*i.e.* R=1, representing the case in all reflected light eventually escapes, and R=0, representing the case in which all reflected light is lost) is small and it is therefore generally valid to employ either assumption. Since the expressions obtained under the T=1 assumption are simpler, they will be used in for the remainder of this description.

For the expected range of the index of refraction for the organic layer -- between 1.6 and 1.8, it can be seen from Equation (1), that the corresponding range for the coupling efficiency, η_{ext}, will be between 0.20 and 0.15, demonstrating the significance of the coupling efficiency in degrading system efficiency -- *i.e.* between 80 and 85 percent of the internally generated light is trapped within the device. The external coupling efficiency has been improved by a factor of 1.9 ± 0.2 by etching grooves in the glass around the OLED to redirect light trapped in the substrate and organic/ITO layers [*See*, G. Gu, *et al.*, *id.*] This method does not lend itself well to the fabrication of device arrays, however, where metal lines and/or circuitry for passive or active matrix drivers would have to cross the deep grooves. This method also has the disadvantage of requiring the etching of finely controlled, non-vertical profiles in the substrate, significantly increasing the complexity of fabrication.

According to the method of the invention, a solution to the light-trapping problem is provided by patterning the back (viewing) side of the substrate in the shape of a sphere with its center at the source of light. Most of the light would then impinge normally on the air-substrate interface, sharply reducing the loss of light due to wave-guiding in the substrate. Such spherical patterning of the substrate is illustrated schematically in Figure 2.

With reference to the figure, the attachment of a sphere to the backside of the substrate, or shaping the substrate into such a spherical form, shown in Figure 2(a) permits the light rays to escape the substrate at much greater angles. The maximum angle of the light ray that is emitted externally is increased from $\theta_{org,\,c1}$ in the planar device to $\theta_{max} = \tan^{-1}(\rho_{lens}/t_{subs})$ in the backside-patterned device of the invention (illustrated in Figure 2(a)). To the extent that θ_{max} is determined by the actual pattern and can be made large, the external coupling efficiency is

increased to $\eta_{ext} = 1 - \cos\theta_{max}$ (arrived at by changing the upper limit of integration in Equation (1)). In the center of the spherical curvature does not directly correspond to the OLED location, then no one can further tune the far field pattern due to refraction effects since the light rays will not be traveling through the lens/air interface (or the shaped substrate/air interface) at normal incidents. Other methods which break the planarity of the back surface of the substrate will also achieve less total internal reflection, and bus increased external efficiency.

Applicants show below a plurality of embodiments for the invention which they have implemented and developed experimental results. Various parameters material to the implementation of those embodiments are summarized in Table 1 hereafter. Three derived parameters shown in Table 1 can best be understood that with reference to Figure 2. The first of these derived parameters is the substrate index (n_{subs}), which completely determines $\theta_{org,\,c1}$ and $\theta_{org,\,c2}$ and therefore also completely determines η_{ext} and η_{subs}. n_{subs} also determines the intensity distribution profile inside the substrate layer, which can be obtained from Equation (3) by replacing n_{air} with n_{subs} [*See*, G. Gu, *et al., id.*]

$$I_{subs}(\theta_{subs}) = \frac{F}{2\pi}\frac{n_{subs}^2\cos\theta_{subs}}{n_{org}^2\sqrt{1-\left(\frac{n_{subs}}{n_{org}}\sin\theta_{subs}\right)^2}}. \qquad (4)$$

$I_{subs}(\theta_{subs})$ is of interest because Equation (3) only describes the external intensity distribution when the substrate is planar. If the substrate forms a hemisphere with the device at its center, for instance, $I_{ext}(\theta_{ff})$ will be equal to $I_{subs}(\theta_{subs})$. In fact, $I_{subs}(\theta_{subs})$ plays a direct role in determining $I_{ext}(\theta_{ff})$ in all cases *except* the special case of a planar substrate. Continuing, the effect of n_{subs} on I_{subs} is to focus the distribution as n_{subs} is increased, until $n_{subs}=n_{org}$, at which point $I_{subs}(\theta_{subs})$ reproduces the isotropic intensity distribution initially generated in the organic layer.

The second of the derived parameters is the maximum angle of light (in the substrate) collected into the lens ($\theta_{subs,\,max}$). This parameter is obtained from the total substrate thickness (t_{subs}) and the lens radius (ρ_{lens}) by the expression,

$\theta_{subs.\ max} = \tan^{-1}(\rho_{lens}/\ t_{subs})$. Assuming $\theta_{subs.\ max}$ is large enough to capture all of the light that would have been transmitted out of the substrate without the lens (i.e. $\theta_{subs.\ max} > \sin^{-1}(n_{air}/n_{subs})$), then any light emitted at angles greater than $\theta_{subs.\ max}$ will be wave-guided in the substrate and lost. Following the same analysis which led to Equation (1), an expression can now be obtained under the same assumption on $\theta_{subs.\ max}$ for the external coupling efficiency for an OLED centered over a spherically shaped substrate,

$$\eta_{ext} = \int_0^{\theta_{subs\ max}} I_{subs}(\theta_{subs})\sin(\theta_{subs})d\theta_{subs} \ \textit{(spherical substrate).} \qquad (5)$$

To demonstrate the significance of $\theta_{subs.\ max}$, consider that if $\theta_{subs.\ max} = 76°$ (i.e. $\rho_{lens} = 4\ t_{subs}$) and $n_{subs} = n_{org}$, that uncoupled 14° represents 24 percent of the light transmitted into the substrate.

The third and final of the derived parameters is the vertical offset of the device from the center of curvature of the lens (d_{offset}). This parameter is of interest because it strongly affects the far field distribution pattern. The analytical expression for I_{ext} when $d_{offset} \neq 0$ can readily be found in the art. For purposes of this discussion, it is sufficient to point out that when the OLED is positioned too far from the lens ($d_{offset} > 0$), I_{ext} will be more focused than I_{subs}, and when the OLED is positioned too closely to the lens ($d_{offset} < 0$), I_{ext} will less focused than I_{subs}. However, over a wide range of offset values, there is only a minor degrading effect on η_{ext} due to $|d_{offset}| > 0$.

Note that the ray used to define the far-field angle, θ_{ff}, of Figure 2(a), is drawn for the d=0 case, while in the diagram, d, the offset between the center of curvature of the lens and the OLED, is drawn as non-zero so that it can be clearly identified. Note also that spherical features implemented as a plastic lens array laminated to a planar substrate are particularly illustrated in Figure 2(b).

While it is noted that the basic substrate-face design has been used before with traditional LEDs, that approach has not previously been applied for the improvement of output coupling in OLEDs. In addition, such an OLED approach would not have been suggested by the LED application. Note as well that the extremely high indices of refraction (e.g. n > 4) found in the emitting materials in

traditional LEDs precluded some of the advantages one can obtain with OLEDs. In particular, by matching the index of the substrate to the index of the emitting material in addition to shaping the substrate, one can potentially eliminate *all* of the external coupling losses in the device, and transparent substrate materials in the appropriate index range (*i.e.* n~ 1.6 – 1.8) are readily available.

The inventors have implemented the approach of the invention for a number of embodiments, which are further described hereafter. The OLEDs that constitute these various embodiments were fabricated on glass and polycarbonate (PC) substrates. The glass substrate consisted of 0.7 mm and 1.1 mm-thick soda lime glass purchased from Applied Films Co. coated with ITO by the manufacturer. The PC substrates consisted of 175 μm-thick sheets purchased from Goodfellows Co., with a 100 nm ITO film deposited on it in an Edwards A306 RF magnetron sputter with 2 mTorr pure Ar gas at 150 W RF power at room temperature. The sputter target was 90% In_2O_3-10% SnO, 3 in. in diameter. The deposition rate was 33 nm/min. The OLEDs were made by spinning on a single poly-(N-vinylcarbazole) (PVK)/2-(4-biphenyl)-5-(4-tert-butylphenyl)-1,3,4-oxadiazole(PBD)/Coumarin 6 (C6) layer, and evaporating a 100 to 200 nm Mg:Ag cathode [Wu]. The index of refraction of the organic layer was measured to be 1.67 by ellipsometry at λ = 634 nm and λ = 830 nm. Typical device size and geometry consisted of a circle 1.75 mm in diameter.

Experiments were performed with six different substrate structures, which are designated Trials 1 through 6 in Table 1. A diagram of the substrate setup (with all relevant parameters identified) is provided in Figure 2(a).

Table 1

Trial	Substrate Material	Lens Material	R_{lens} (mm)	ρ_{lens} (mm)	t_{subs} (mm)	θ_{max}	d (mm)	I_{normal}/I_0 ± 0.1	F/F_0 ± 0.1
1	Glass (*n=1.51*)	N/A	N/A	N/A	0.7	N/A	N/A	1.0	1.0
2	Glass (*n=1.51*)	Glass (*n=1.51*)	3.4	3.4	0.7	78°	+1.0	3.6	2.0
3	Glass (*n=1.51*)	Glass (*n=1.51*)	3.4	3.4	2.0	60°	+2.3	9.5	1.6
4	Glass (*n=1.51*)	Silicone (*n=1.41*)	2.7	2.4	1.9	51°	+0.6	2.1	1.6
5	PC (*n=1.61*)	N/A	N/A	N/A	1.0	N/A	N/A	1.0	1.0
6	PC (*n=1.61*)	Epoxy (*n=1.60*)	2.7	2.4	1.0	67°	-0.3	1.6	3.0

Substrate and lens parameters (as defined in Figure 2a) for different external coupling experiments. I_{normal}/I_0 and F/F_0 represent the ratio of normal emission intensity and total emission intensity respectively to the results obtained for identical devices fabricated on planar substrates of

the same substrate material. The total emission intensity measurement does not include edge emission.

In Trial 1, unmodified planar glass substrates were used. In Trials 2 and 3, glass substrates with attached glass condenser lenses purchased from Edmund Scientific Co. were used. In Trial 4, glass substrates with attached molded silicone lenses were used. In these latter three trials, the lenses were attached to the substrate using index matching gel purchased from FIS Co.. When necessary, the substrate thickness was increased by gluing on extra glass slides with the same index matching gel. The silicone lenses were molded in a Teflon block with ball-milled indentations with GE RTV615 silicone ($n = 1.405$). In Trials 5 and 6, PC substrates were used. In Trial 5, the standard planar substrate was employed, while in Trial 6, molded epoxy lenses were attached to the PC substrate. The epoxy lenses were fabricated using the same mold as described above with Master Bond EP42HT two-component epoxy ($n = 1.61$). The lenses were glued to the substrate with uncured epoxy. For each trial, the far field intensity pattern was measured using a large area (1 cm diameter) Si photodetector at a distance of 10 cm away from the device at 6° increments between 0° (normal) and 90°.

The three derived parameters previous described and shown in Figure 2(a) -- substrate index (n_{subs}), maximum angle of light collected into the lens ($\theta_{subs,\ max}$), and vertical offset of the device from the center of curvature of the lens (d_{offset}) -- all play a critical role in determining the total emitted flux and the external intensity distribution in that experiment. With these parameters in hand, it is a simple matter to evaluate the experimental results. The normal and total emitted flux measured in each trial is listed in Table 1. Plots of the measured emitted flux at each angle for each trial are provided in Figures 3b and 3c. The total emitted flux results are initially addressed.

In the trials with glass substrates (Trials 2 – 4), the total emitted flux was increased by a factor of between 1.6 and 2.0 ± 0.1. These results are consistent with the analytical values obtained from Equations (5) and (1), where it is noted that in Trial 3, the large d_{offset} is expected to slightly degrade the effectiveness of the lens. (Because $\theta_{subs,\ max} < \sin^{-1}(n_{silicone}/n_{subs})$, the lower index of the silicone does not have a significant effect on the results.) In the trial with the PC substrate

and an epoxy lens (Trial 6), the total emitted flux was increased by a factor of 3.0 ± 0.1 over the planar PC substrate case (Trial 5), which is again consistent with the analytical values obtained using Equations (5) and (1). It is noted that Equation (1) predicts that the planar cases for the PC and glass substrates should be identical, it can be observed in Figure 3c that the two cases (Trials 1 and 5) are indeed effectively identical within experimental uncertainties of the trials. This provides experimental justification for comparing the results obtained for PC substrates with those for glass substrates.

The emitted flux distribution results are now addressed. In all of the results, one can correlate the normal emitted flux with the value for d_{offset}. Trial 3 represents one extreme: d_{offset} = 2.3 mm and $I_{normal}/I_0 = 9.5$. Trial 6 represents the other extreme: d_{offset} = -0.3 mm and $I_{normal}/I_0 = 1.6$. Since different substrate and lens materials were used in each trial, the value of I_{normal}/I_0 is not *solely* determined by d_{offset}; however, the analytical expression for I_{ext} and our results demonstrate that for the normal 6° cone, d_{offset} is the dominant parameter. In Figures 3b and 3c, the complete emitted intensity distribution results are presented. These results again demonstrate the focusing effect of increasing d_{offset}. In addition, the results from Trial 6 demonstrate just how effective using a lens with a high index substrate can be at reproducing the isotropic intensity distribution generated in the organic layer -- the emitted flux remains effectively constant from 0° to 72° in this trial.

It is noted finally that, in Figures 3(a) and 3(b), one sees essentially perfect correlation between the data for the planar glass substrate (Trial 1) and the two different refraction models described above. Furthermore, the data significantly deviates from the Lambertian distribution results, further reinforcing the validity of the refraction models presented in this paper.

Having thus described the invention in detail, it is to be understood that the foregoing description is not intended to limit the spirit and scope thereof. What is desired to be protected by Letters Patent is set forth in the appended claims.

CLAIMS

What is claimed is:

1. A light emitting device. said device comprising:

a transparent substrate having a first surface and a second surface;

a conductive transparent layer disposed on said first surface of said substrate;

an organic layer disposed on said conductive oxide layer: and

a top contact disposed on said organic layer;

wherein a contour of said second surface of said substrate is caused to assume a non planar form.

2. The light emitting device of claim 1 wherein said non-planar form is spherical.

3. The light emitting device of claim 1 wherein said second surface contour is caused to assume a non-planar form by moulding said substrate surface.

4. The light emitting device of claim 1 wherein said second surface contour is caused to assume a non-planar form by laminating a first surface of a second transparent layer having a non-planar second surface to said second surface of said substrate.

5. A method for increasing light emissivity for organic light emitting diodes (OLED), wherein said OLED is disposed on a first surface of a transparent substrate, said method comprising the step of:

causing a second surface of said substrate to assume a non-planar form.

6. The method for increasing light emissivity for OLEDs of claim 5 wherein said non-planar form is spherical.

7. The method for increasing light emissivity for OLEDs of claim 5 wherein said second surface contour is caused to assume a non-planar form by moulding said substrate surface.

8. The method for increasing light emissivity for OLEDs of claim 5 wherein said second surface contour is caused to assume a non-planar form by laminating a first surface of a second transparent layer having a non-planar second surface to said second surface of said substrate.

9. A method for constructing a light emitting device comprising the steps of:

providing a transparent substrate having a first and a second surface;

depositing a conductive transparent layer on said first surface of said substrate;

depositing an OLED layer on said conductive transparent layer; and

causing a contour of said second surface of said substrate to assume a non-planer form.

10. The method for constructing a light emitting device of claim 9 wherein said non-planar form is spherical.

11. The method for constructing a light emitting device of claim 9 wherein said second surface contour is caused to assume a non-planar form by moulding said substrate surface.

12. The method for constructing a light emitting device of claim 9 wherein said second surface contour is caused to assume a non-planar form by laminating a first surface of a second transparent layer having a non-planar second surface to said second surface of said substrate.

13. A light emitting device, said device comprising:

a transparent substrate having a first surface and a second surface;

an OLED layer disposed on said first surface of said substrate;

wherein said second surface of said substrate is molded to a non-planar form.

14. The light emitting device of claim 13 wherein said non-planar form is spherical.

15. A light emitting device, said device comprising:

a transparent substrate having a first surface and a second surface;

an OLED layer disposed on said first surface of said substrate;

wherein a contour of said second surface is caused to assume a non-planar form by laminating a first surface of a second transparent layer having a non-planar second surface to said second surface of said substrate.

16. The light emitting device of claim 15 wherein said non-planar form is spherical.

17. A method for increasing light emissivity of a light emitting device, wherein said light emitting device includes at least two OLEDs disposed on a first surface of a transparent substrate, said method comprising the step of:

causing a contour of selected portions of a second surface of said substrate to assume a non-planar form, said selected portions being selected to be in optical alignment with a light output from ones of said at least two OLEDs.

18. The method for increasing light emissivity of claim 17 wherein wherein said non-planar form is spherical.

19. The method for increasing light emissivity of claim 17 wherein said selected second surface contours are caused to assume a non-planar form by moulding said substrate surface.

20. The method for increasing light emissivity of claim 17 wherein said selected second surface contours are caused to assume a non-planar form by laminating a first surface of a second transparent layer having a non-planar second surface to said second surface of said substrate.

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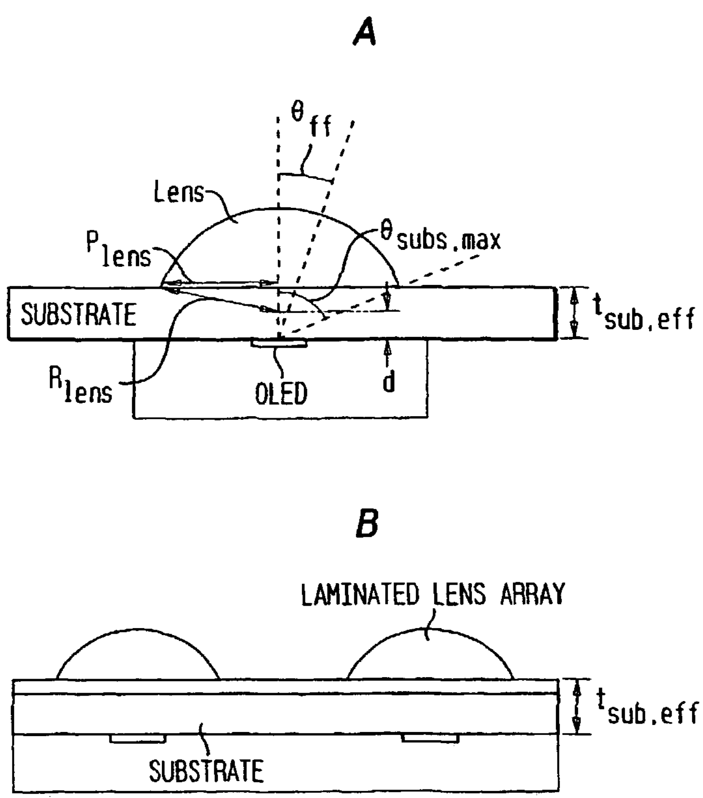
[Continued on next page]

(54) Title: ORGANIC LIGHT EMITTING DIODE HAVING SPHERICAL SHAPED PATTERNS



(57) Abstract: A approach is provided for increasing the emission intensity of an organic light emitting diode (OLED) and the total external emission efficiency for an OLED at a normal viewing angle. With the approach of the invention, they have been increased by factors of 9/6 and 3.0 respectively by applying spherically shaped patterns to the back of the device substrate. The inventive approach captures light previously lost to wave-guiding in the substrate and, with proper choice of substrate, light previously lost to wave-guiding in the organ/anode layers.

WO 01/33598 A1

1/3

FIG. 1

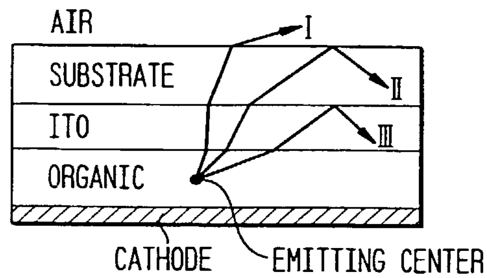


FIG. 2A

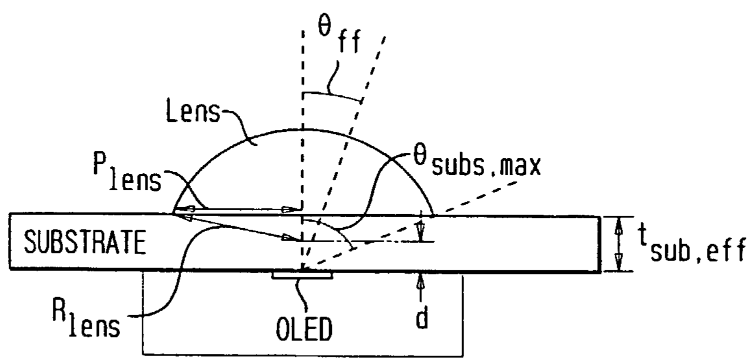


FIG. 2B

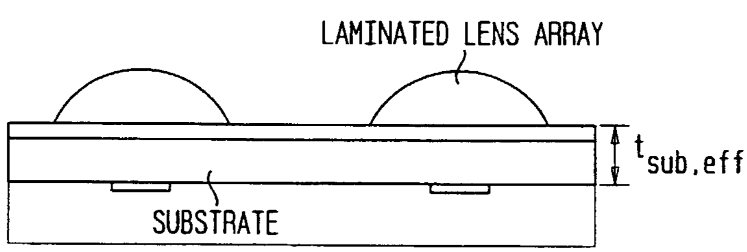


FIG. 3A

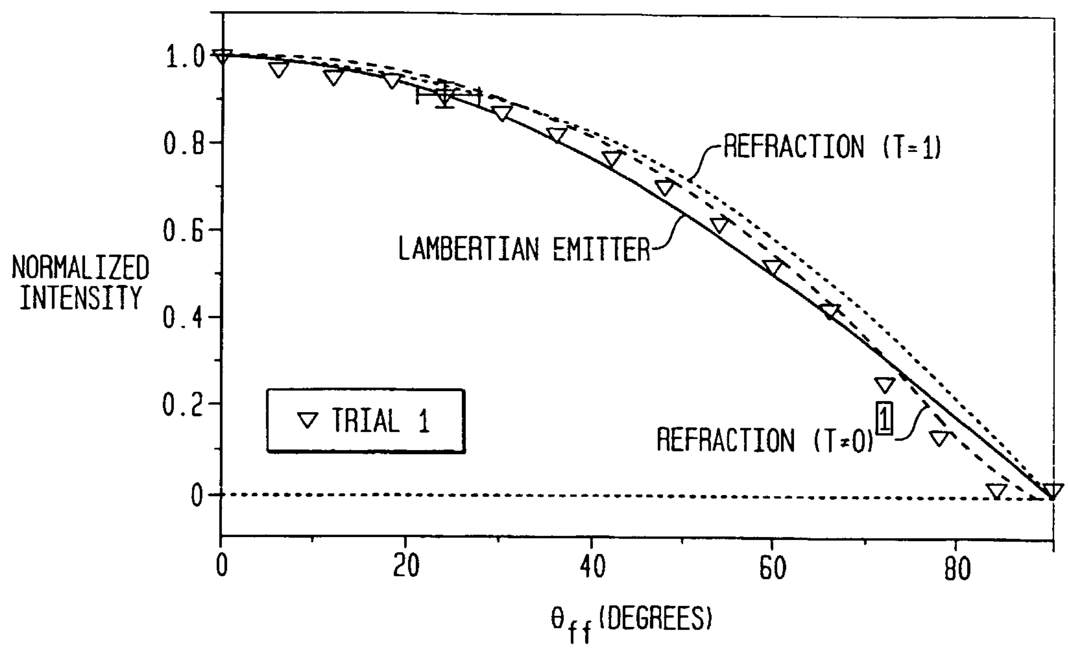

1.0
0.8
0.6
0.4
0.2
0
NORMALIZED INTENSITY
REFRACTION (T=1)
LAMBERTIAN EMITTER
TRIAL 1
REFRACTION (T=0)
1
0
20
40
60
80
θ_{ff} (DEGREES)

FIG. 3B

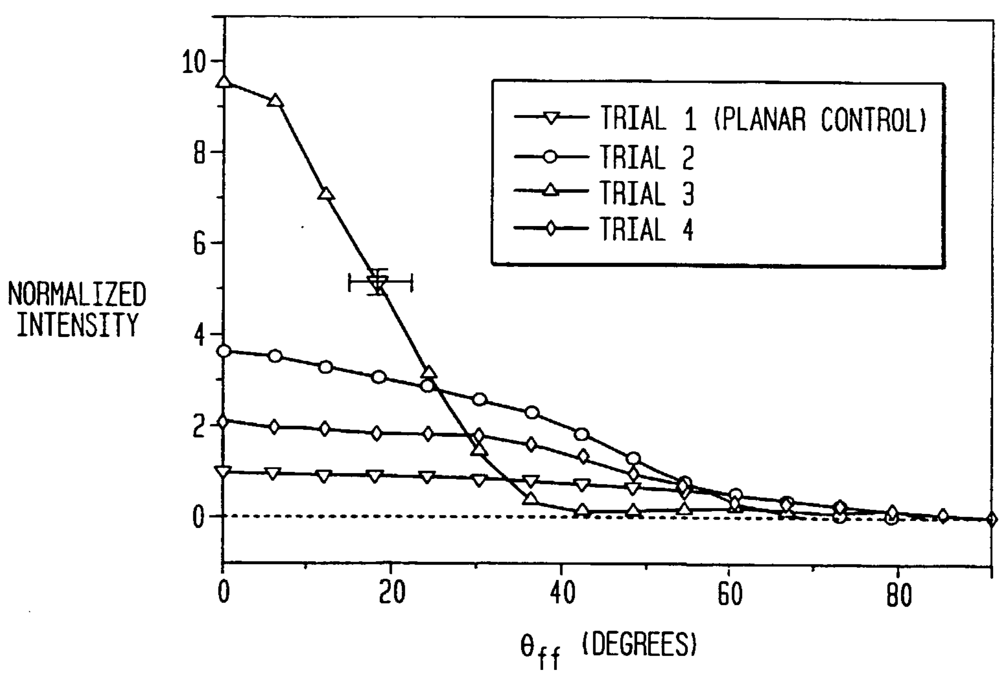
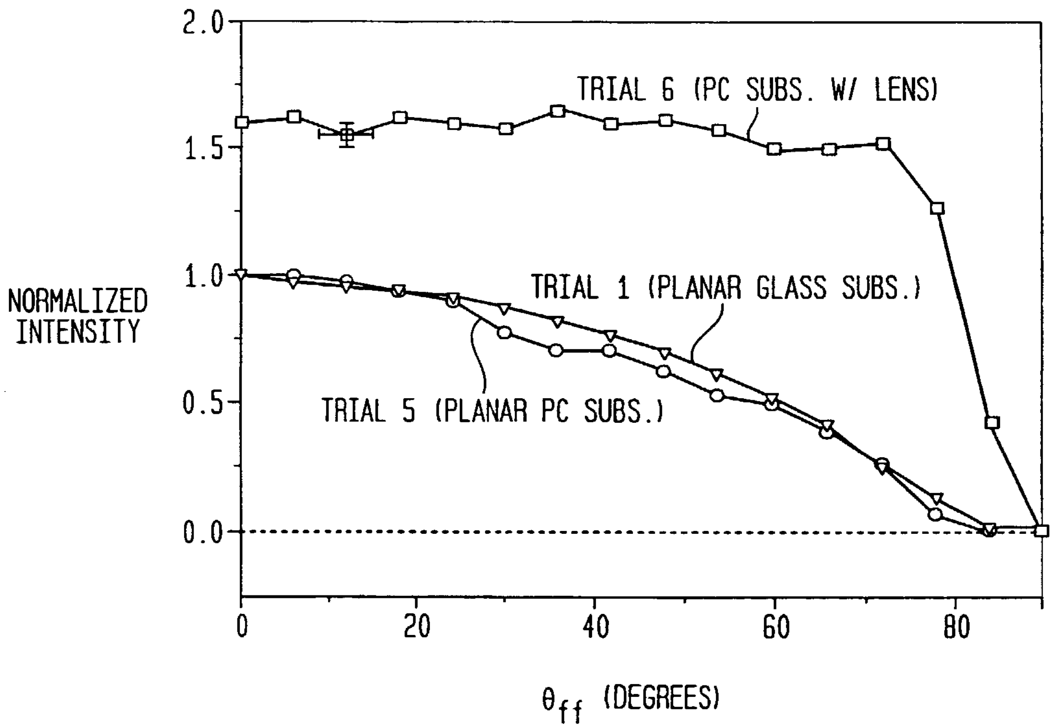

10
8
6
4
2
0
NORMALIZED INTENSITY
TRIAL 1 (PLANAR CONTROL)
TRIAL 2
TRIAL 3
TRIAL 4
0
20
40
60
80
θ_{ff} (DEGREES)

FIG. 3C


2.0
1.5
1.0
0.5
0.0
NORMALIZED INTENSITY
TRIAL 6 (PC SUBS. W/ LENS)
TRIAL 1 (PLANAR GLASS SUBS.)
TRIAL 5 (PLANAR PC SUBS.)
0
20
40
60
80
θff (DEGREES)

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7616/42/5

Declaration and Power of Attorney For Patent Application

English Language Declaration

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled
Increased Emission Efficiency for Organic Light Emitting Diodes

the specification of which

(check one)

☐ is attached hereto.

☒ was filed on ____________ as United States Application No. or PCT International Application Number **PCT/US00/29822**
and was amended on ____________
(if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d) or Section 365(b) of any foreign application(s) for patent or inventor's certificate, or Section 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s) | Priority Not Claimed

(Number)	(Country)	(Day/Month/Year Filed)	☐
(Number)	(Country)	(Day/Month/Year Filed)	☐
(Number)	(Country)	(Day/Month/Year Filed)	☐

I hereby claim the benefit under 35 U.S.C. Section 119(e) of any United States provisional application(s) listed below:

60/162,552	10/29/99
(Application Serial No.)	(Filing Date)
(Application Serial No.)	(Filing Date)
(Application Serial No.)	(Filing Date)

I hereby claim the benefit under 35 U. S. C. Section 120 of any United States application(s), or Section 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. Section 112, I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, C. F. R., Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. *(list name and registration number)*

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